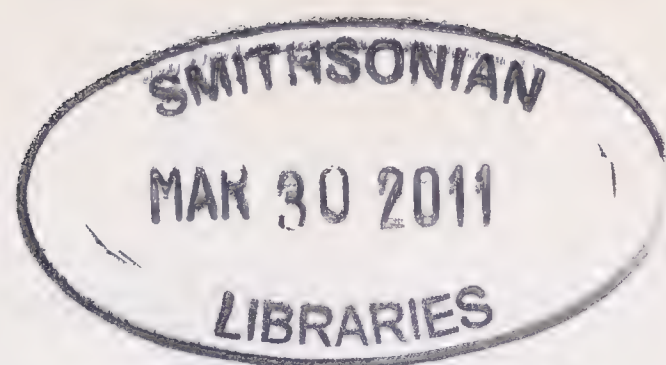




## AUSTRALOCOSMICA, A NEW GENUS OF LAND SNAILS FROM THE KIMBERLEY, WESTERN AUSTRALIA (EUPULMONATA, CAMAENIDAE)

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### ABSTRACT

The Western Australian Kimberley region harbours a diverse fauna of camaenid land snails characterised by marked patterns of narrow range endemism. A recent survey of previously poorly known areas along the Kimberley coast has resulted in the discovery of a number of further, yet undescribed camaenid taxa. One of these, the genus *Australocosmica*, is newly described herein based on comparative studies of genital anatomy, shell and radular morphology, and analyses of partial sequences of the mitochondrial marker 16S rRNA. *Australocosmica* is characterised by a broadly conical to semi-globose shell with moderately elevated spire, well-rounded, convex whorls that are separated by a deeply incised suture, and a sculpture of dense, regularly spaced axial ribs. The most distinguishing feature of the inner penial anatomy is the presence of a furrowed, collar-like vergic papillum forming the entrance of the vas deferens into the lumen of the penial chamber. Three new species, ***Australocosmia augustae***, ***A. sanctumpatriciusae***, and ***A. vulcanica***, are described based mainly on differences in penial anatomy. All species are well differentiated by uncorrected pair-wise p-distances of 15% to 20% in the 16S rRNA gene. Similar to most camaenids in the Kimberley region, species of *Australocosmica* are narrow-range endemics being restricted to single islands, sometimes including the immediately adjacent mainland coast.

Key words: Helicoidea, endemism, anatomy, mitochondrial differentiation, diversity.

### INTRODUCTION

The Kimberley region of northwestern Australia is arguably one of the most remote regions of the continent. Due to its rugged landscape formed by ancient rocky ranges and the sparse infrastructure, many parts of this region, which covers an area larger than Germany, are very difficult to access. Under these conditions, it is no surprise that the documentation of the biota of vast areas has remained incomplete and that our knowledge especially with regard to the occurrence of narrow-range invertebrates is still very patchy. Camaenid land snails are such a group of animals with generally restricted ranges. In addition, these animals are difficult to collect, spending most of the year aestivating buried in the soil or hidden in rock crevices.

Morphology-based revisions have greatly contributed to a consistent taxonomy of the Western Australian Camaenidae based on comprehensive comparative analyses and have highlighted their diversity as well as marked patterns of endemism (Solem, 1979,

1981a, b, 1984). Essentially based on survey work of rainforest patches along the Kimberley coast, conducted between 1987 and 1988, Solem (1991) listed about 120 camaenid species, and a large proportion of them have remained undescribed. During an on-going biological survey conducted by the Western Australian Department of Environment and Conservation, land snails were collected on 22 larger islands off the Kimberley coast. The land snail fauna of most of these continental islands was completely unknown, and analyses of a data set of partial sequences of the mitochondrial 16S rRNA gene have demonstrated that these islands harbour substantial numbers of new candidate species that have not been recorded earlier (Köhler, 2009). These candidate species were identified by uncorrected pair-wise p-distances of at least 3% or usually much more following the approach described by Vieites et al. (2009) for the delimitation of Madagascan frog species by use of molecular markers. However, the actual taxonomic status of these candidate species awaits confirma-



tion by morphological examination. The study of a comparatively small proportion of newly collected samples from the Kimberley Islands has indeed revealed corresponding levels of molecular and morphological differentiation in camaenids from the Kimberley both on the species and genus level. Accordingly, it has been shown that the genital anatomy provides the most reliable means to delimitate taxa. In addition, the camaenid species are generally well differentiated also on the molecular level with interspecific distances usually exceeding 10% in 16S. The on-going taxonomic work on the Camaenidae in the Kimberley has resulted in the identification of several new species of *Amplirhagada* Iredale, 1933, by Köhler (2010a) and the description of two new genera and several new species of camaenids from islands in the north Kimberley (Köhler, 2010b). However, the status of many additional undescribed taxa awaits clarification by comparative morphological studies. The present work is concerned with the study of a new genus that was preliminarily recognised by Solem (1991), who listed two potentially new genera in the Kimberley. These genera have remained unstudied and unnamed since. The novelty of one of them, referred to by Solem (1991) as “Ngen1” has recently been confirmed by a comparative study based on morphological and molecular data (Köhler, 2010b) and been described under the name *Kimberleydiscus* Köhler, 2010. It is only known from Bigge Island. The present work contains a comparative study of species of the second undescribed group referred to by Solem (1991) as “Ngen2”. Solem (1991) attributed two unnamed species to this group from the mainland of the western Kimberley near the Saint George Basin, about 400 km NE of Broome. Survey work in 2009 yielded a number of samples of additional species from the same group, as recognised by its shell, on which the present work is based.

## MATERIAL AND METHODS

This study is based on ethanol preserved specimens and dry shell material collected during the Kimberley Island Survey (KIS) of the Department of Environment and Conservation, Western Australia (DEC) in 2009. Types are deposited in the Western Australian Museum, Perth (WAM) and the Australian Museum, Sydney (AM).

The observed differentiation in morphological and mitochondrial characters is herein used to

formulate hypotheses on the identity of species as reproductively isolated units (i.e., to delineate species taxa) according to the biological species concept (Mayr, 1942).

Morphological descriptions focus on characters of the shell, the mantle cavity, the genital organs and the radula. Morphometric shell parameters, such as height of shell (H), diameter of shell (D), height of last whorl (LW), and width of umbilicus (U) were measured with callipers precise to 0.1 mm. The numbers of whorls of shell (N), including the protoconch, were counted as described by Barker (1999: fig. 6). All mature shells per lot were measured (as recognized by a fully developed apertural lip) as long as their spire and aperture were complete.

Anatomy of mantle and genital organs was studied using a microscope with drawing mirror. The final inking of drawings was done by Martin Püschel. Radulae and jaws were extracted manually, cleaned by soaking in 10% KOH solution for about six hours, followed by rinsing in water and ethanol. They were mounted on carbon specimen tabs for electron scanning microscopy. Radular dentition formula gives the numbers of teeth per row as follows: C (central row of teeth) + number of lateral rows of teeth + number of transitional rows of teeth + number of marginal rows of teeth. Usually, two to three specimens per sample were studied in order to ensure that the described features are consistent within taxa.

DNA was extracted from small pieces of foot muscle by use of a QIAGEN DNA extraction kit for animal tissue following the standard procedure of the manual. A fragment of the mitochondrial 16S rRNA gene (16S) was amplified by PCR using the primers 16Scs1 (Chiba, 1999) and 16Sbd1 (Sutcharit et al., 2007). Reactions were performed under standard conditions with an annealing step of 90 s at 55°C. Sequences were aligned by use of Clustal X vs. 2.0 (Larkin et al., 2007) under default settings. The aligned sequence data set comprised 5 sequences and was trimmed to a total length of 827 bp. A sequence of *Xanthomelon obliquirugosa* (E. A. Smith, 1894) was used as out-group to root the tree. The phylogenetic tree was reconstructed by application of Maximum Likelihood (ML) using the software Treefinder vs. October 2008 (Jobb et al., 2004). Prior to the ML analysis, a likelihood ratio test was performed as implemented in Treefinder to infer which model of sequence evolution fits best the data. Nodal support of the topology was inferred by calculating Expected-



TABLE 1. Shell dimensions (in mm). Given are maxima and minima (average  $\pm$  standard deviation) of shell height (H), shell diameter (D), height of last whorl (LW) [each in mm], number of whorls (N), and height/diameter ratio (H/D) (n = number of measured shells).

| Taxon                                 | H                             | D                             | LW                            | N                          | H/D                            |
|---------------------------------------|-------------------------------|-------------------------------|-------------------------------|----------------------------|--------------------------------|
| <i>A. augustae</i> Holotype           | 15.3                          | 17.5                          | 11.5                          | 5.2                        | 0.87                           |
| Paratypes (n = 15)                    | 12.7–16.3<br>(14.5 $\pm$ 1.1) | 15.3–18.2<br>(16.8 $\pm$ 0.8) | 9.8–12.3<br>(11.1 $\pm$ 0.7)  | 4.7–5.2<br>(5.0 $\pm$ 0.2) | 0.80–0.93<br>(0.86 $\pm$ 0.04) |
| <i>A. sanctumpatriciusae</i> Holotype | 13.0                          | 15.5                          | 9.5                           | 4.6                        | 0.84                           |
| Paratypes (n = 12)                    | 11.4–13.2<br>(12.3 $\pm$ 0.5) | 15.0–16.4<br>(15.9 $\pm$ 0.5) | 9.2–10.4<br>(9.6 $\pm$ 0.3)   | 3.9–4.7<br>(4.4 $\pm$ 0.2) | 0.73–0.82<br>(0.77 $\pm$ 0.03) |
| Non-types, mainland (n = 17)          | 9.2–12.3<br>(11.0 $\pm$ 0.7)  | 14.6–17.8<br>(15.6 $\pm$ 0.9) | 7.8–9.5<br>(8.8 $\pm$ 0.4)    | 4.2–4.6<br>(4.4 $\pm$ 0.1) | 0.63–0.76<br>(0.71 $\pm$ 0.04) |
| <i>A. vulcanica</i> Holotype          | 11.1                          | 13.9                          | 8.5                           | 4.2                        | 0.80                           |
| Paratypes (n = 32)                    | 9.4–11.5<br>(10.4 $\pm$ 0.6)  | 13.1–15.0<br>(13.8 $\pm$ 0.4) | 7.6–9.0<br>(8.3 $\pm$ 0.3)    | 3.7–4.7<br>(4.3 $\pm$ 0.2) | 0.69–0.81<br>(0.75 $\pm$ 0.03) |
| <i>A. spec A</i> (n = 6)              | 12.9–14.6<br>(13.4 $\pm$ 0.6) | 14.6–16.7<br>(15.3 $\pm$ 0.7) | 9.7–11.0<br>(10.2 $\pm$ 0.5)  | 4.5–5.2<br>(4.7 $\pm$ 0.2) | 0.81–0.95<br>(0.87 $\pm$ 0.04) |
| <i>A. spec B</i> (n = 2)              | 14.0–14.8<br>(14.4 $\pm$ 0.4) | 17.7–17.8<br>(17.8 $\pm$ 0.1) | 11.2–11.7<br>(11.5 $\pm$ 0.3) | 4.6–5.6<br>(5.1 $\pm$ 0.5) | 0.79–0.84<br>(0.81 $\pm$ 0.02) |

Likelihood Weights of Local Rearrangements (LR-ELW) (Strimmer & Rambaut, 2002) and bootstrapping (Felsenstein, 1985), each with for 500 replicates. Pair-wise p-distances were calculated under the option ‘pair-wise deletion’ of gaps using the software MEGA (Tamura et al., 2007). Sequences were submitted to Gen-Bank (Acc. Nos. HM043745-50).

Repositories: AM, Australian Museum, Sydney ; FMNH, Field Museum of Natural History, Chicago, Illinois; WAM, Western Australian Museum, Perth.

SYSTEMATIC PART

Gastropoda: Heterobranchia: Stylommato-  
phora: Camaenidae  
Pilsbry, 1895

*Australocosmica*, gen. nov.

Type Species: *Australocosmica augustae*,  
sp. nov.

Etymology: Derived from the words australe  
(Latin, south) and cosmica (Latin, world); of  
feminine gender.

Description: *Shell* between 9 to 17 mm in height  
and 13 to 18 mm in diameter (Table 1), with

broadly conical to semi-globose shape and moderately elevated spire. Whorls wide in cross-section, convex, with well-rounded to slightly angulate periphery, slightly shouldered underneath deeply incised suture. Sculpture of pronounced, dense, regularly spaced axial ribs. Aperture simple, rounded, no traces of nodes, with thinly callued parietal wall. Outer lip thin, slightly expanded. Colour of shell yellowish brown to brownish-horn. Mantle roof with black mottled to spotted pigmentation. Vas deferens enters penial complex apically, connecting to lumen of penial chamber through a conspicuously thickened, furrowed, collar-like vergic papillum. No epiphallus present. Penis sheath well developed, comparatively thick, reaching from base to well above apex of penis. Inner penial wall may support marked longitudinal pilasters, dense pustulation, or a combination of both. Vagina more or less tubular, usually only slightly inflated. Spermatheca free, connected to spermoviduct by delicate connective tissue, reaching base of uterus. Albumen gland elongate. Talon situated within anterior quarter of albumen gland. Species aestivate as free sealers.

Comparative Remarks: Among Kimberley camaenids, somewhat similar uniformly yellowish brown, broadly conical shells with a regular, fine axial sculpture are found in



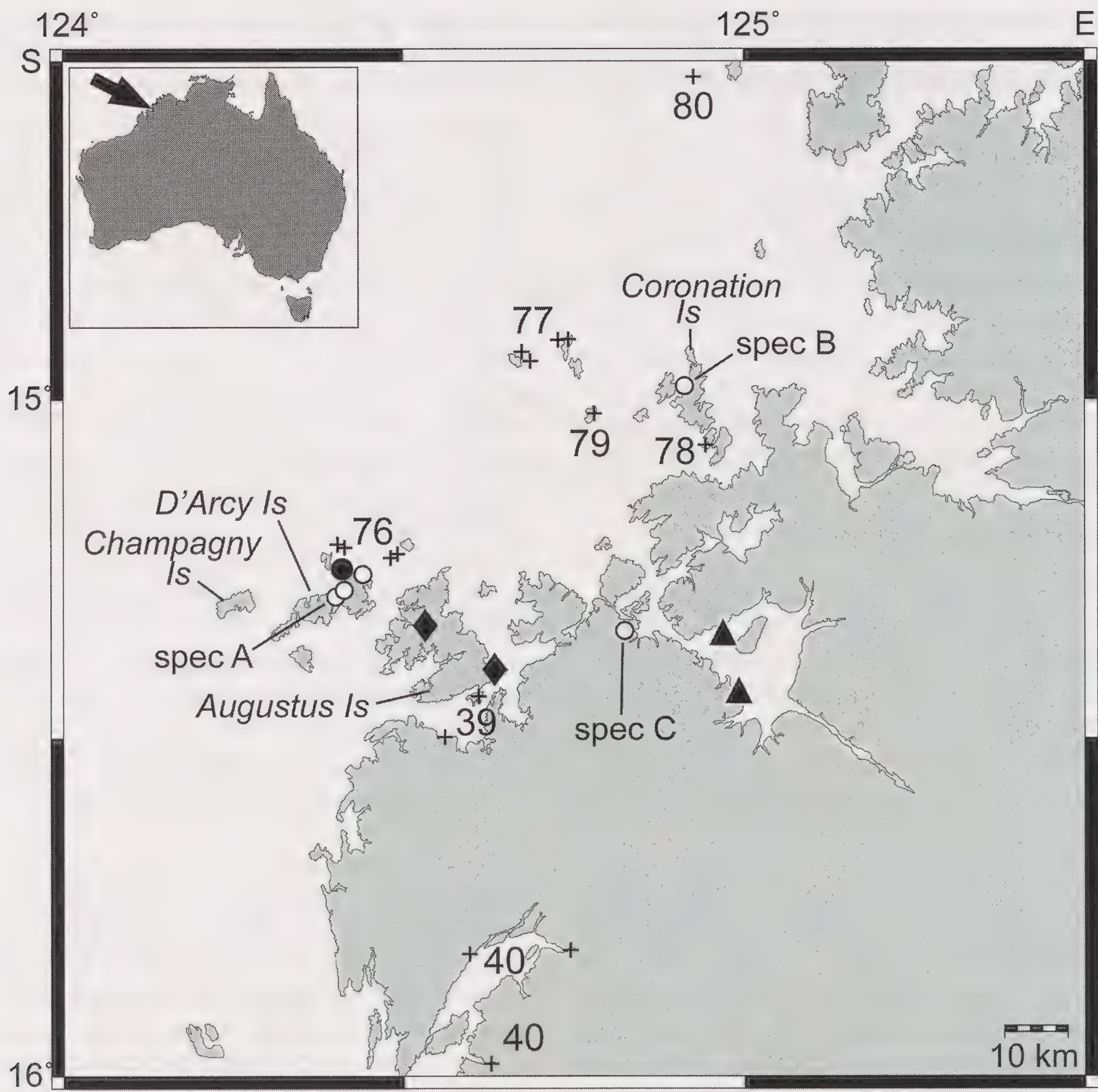


FIG. 1. Distribution map of *Australocosmia* showing occurrences of species in the north-western Kimberley. Species described herein: ◆ – *Australocosmia augustae*, n. sp., ▲ – *Australocosmia sanctumpatriciusae*, n. sp., ● – *Australocosmia vulcanica*, n. sp. Species not described herein: ○ – dry shells of *Australocosmia* spec A-C collected during the Kimberley Island Survey, + - localities of further undescribed species; material housed with the FMNH (species ID numbers and taxon delimitation by Alan Solem).

some species of *Kimboraga*, *Quistrachia*, and *Amplirhagada*. Shells of *Kimboraga* and *Quistrachia* differ by a more rounded shape, fewer and flatter whorls, not as deeply incised suture and markedly inflated body whorl. Only few *Amplirhagada* species have a similar axial sculpture, such as *A. soleimana* Köhler, 2010, and *A. indistincta* Köhler, 2010, from Middle and Southwest Osborn Islands, respectively. However, shells of *Amplirhagada* tend to be flatter (lower spire, larger diameter), which results in different H/D ratio. Their umbilicus is frequently larger and their colour lighter with brown spiral bands usually

being visible. *Kimboraga*, *Quistrachia*, and *Amplirhagada* also differ in certain details of their penial anatomy. The peculiarly elevated, collar-like vergic papillum that connects the vas deferens with the lumen of the penial chamber is the most conspicuous feature differentiating species of *Australocosmia* from other Western Australian camaenids.

Distribution (Fig. 1): Currently known only from coastal portions of the mainland along the gulfs of the St. George Basin and George Water, Prince Regent Region, as well as from various islands in the York and Camden



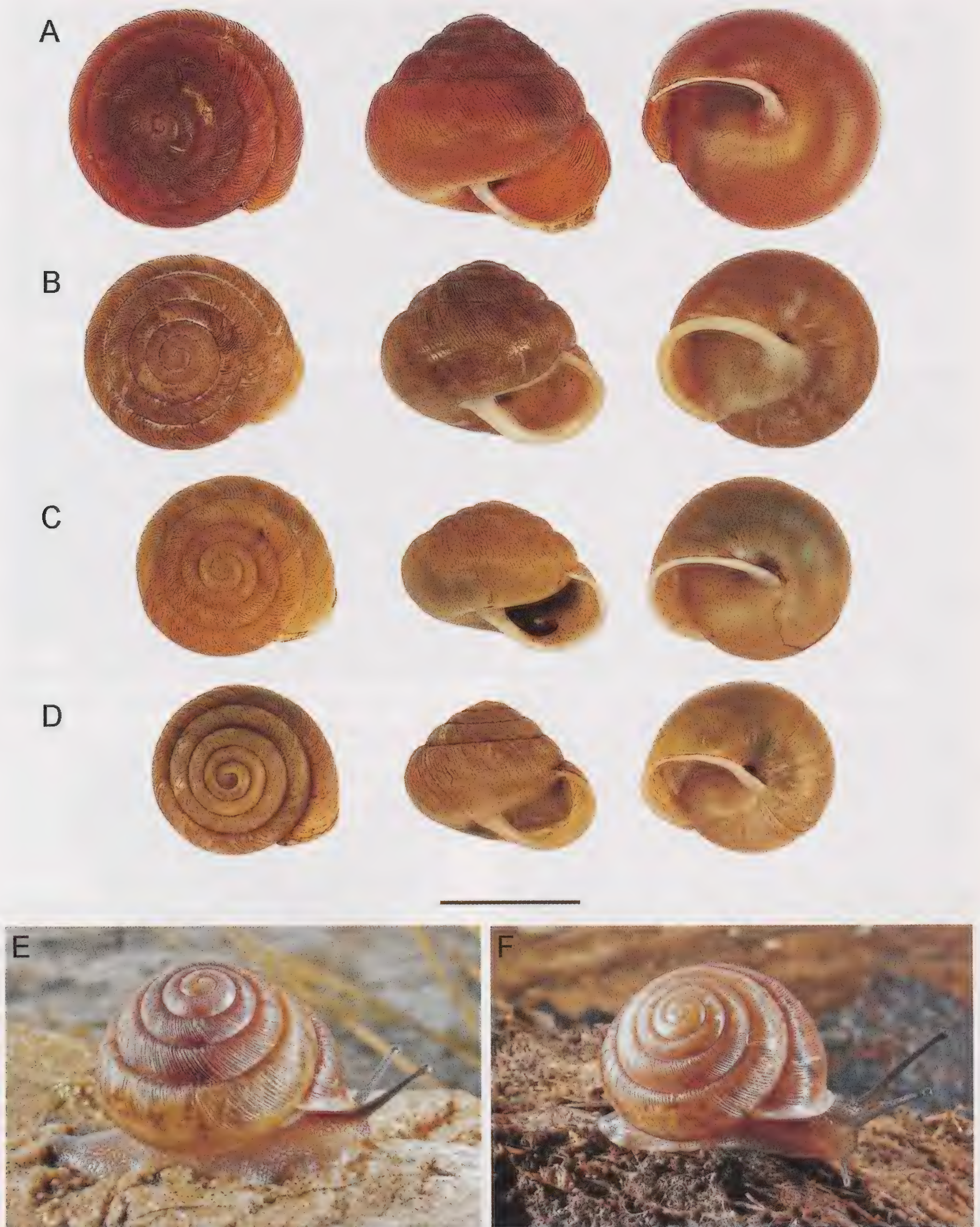


FIG. 2. Shells of the new species of *Australocosmica*, n. gen. A: Holotype of *Australocosmica augustae*, n. sp. WAM S34667; B: Holotype of *Australocosmica sanctumpatriciusae*, n. sp. WAM S34666; C: Shell of *A. sanctumpatriciusae* from the mainland opposite of St. Patrick Island WAM S49022; D: Holotype of *Australocosmica vulcanica*, n. sp. WAM S34668. Scale bar = 10 mm; E: Living specimen of *Australocosmica augustae*, n. sp.; F: Living specimen of *Australocosmica sanctumpatriciusae*, n. sp. (E and F not to scale).



Sounds and Brunswick and Hanover bays off the coast. Next to the three species described here, dry shell material of species attributed to the same genus was collected at a number of other localities in this area by Vince Kessner (Adelaide River, Northern Territory), who kindly provided the locality data. Samples of additional, likely congeneric species are deposited with the Field Museum, Chicago, but were not studied by the present author.

***Australocosmica augustae*, sp. nov.**

Type Locality: Western Australia, NW Kimberley, Bonaparte Archipelago, Camden Sound, NW section of Augustus Island, 15°20'11"S, 124°31'10"E (KIS 1-67). Vine thicket in a valley on moderately steep W facing slopes at base of sandstone cliffs; active on ground at night after rain (leg. V. Kessner, 13.02.2009).

Holotype: (Fig. 2A). WAM S34667 (preserved specimen).

Paratypes: WAM S37635 (ten preserved specimens), AM C.465175 (five preserved specimens).

Additional, non-type Material: Southern section of Augustus Island, 15°23'52"S, 124°38'30"E: WAM S 37633 (preserved juvenile), WAM S49023 (eight dried, mostly worn shells), AM C.465176 (five mostly worn shells). Augustus Island, gully in SE corner of island, 15°23'45"S, 124°37'47"E: WAM S37634 (preserved specimen).

Etymology: The species epithet refers to the name Augustus.

Description: *Shell* (Figs. 2A, 3A–D) size between about 13 and 16 mm in height and 15 to 18 mm in diameter (Table 1), broadly conical to semi-globose, with moderately elevated spire, thin (translucent) in juveniles to

thick in adults. Whorls wide in cross-section, convex, with well-rounded periphery, slightly shouldered underneath deeply incised suture. Sculpture of pronounced, dense, regularly spaced axial ribs. Aperture simple, rounded, no traces of nodes, with thinly calved parietal wall, forming an angle relative to the horizontal of 45° in adults and 30° in juveniles. Outer lip thin, slightly expanded. Umbilicus completely obscured by columellar reflection or narrowly winding, about 1 mm in diameter. Colour uniformly brownish-horn, inner lip whitish. Periostracum glossy. Protoconch about 3.5 mm in diameter with 1.5 whorls, almost smooth, with very fine, indistinct axial pustulations, transition to teleoconch indistinct.

*Pallial Cavity*: Deep, extending about one whorl. Mantle with black mottled pigmentation. Kidney extending half length of pallial cavity, forming a narrow band.

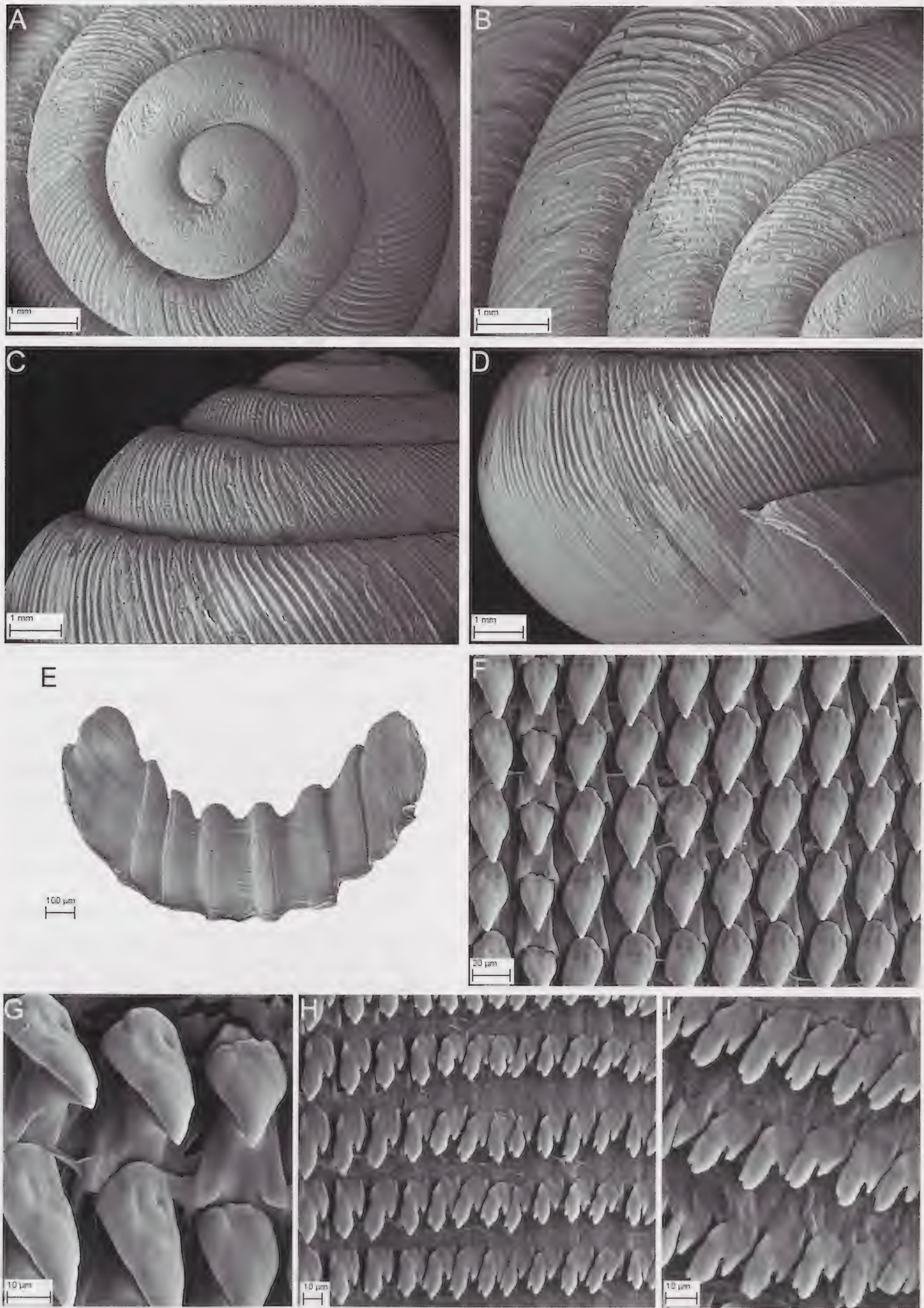
*Digestive Anatomy* (Fig. 3E–I): Jaw consisting of eight regular, rather narrow plates ( $n = 2$ ). Radula in average  $3.2 \pm 0.8$  mm long with  $100 \pm 14$  rows of teeth ( $31.3 \pm 3.4$  rows/mm) ( $n = 2$ ). Tooth formula = C + 14 + 2 + 14 - 15. Central teeth with sharply pointed, slender mesocone that extends to more than half of basal plate; ectocones absent. Lateral teeth with sharply pointed, elongately ovate mesocone, about as long as base of tooth; endocones and ectocones vestigial. Marginal teeth multicuspic, mesocone and endocone similar in length, ectocone smaller than endocone, occasionally subdivided.

*Genital Anatomy* (Figs. 4, 5): Penis straight, of more or less of same length as anterior part of oviduct (= vagina and free oviduct). Penial retractor muscle longer than penis; attached to penial apex near entering of vas deferens. Penial sheath well developed, extending entire length, thin proximally, thick distally. No well-developed epiphallus present. Vas deferens enters penial sheath near apical portion of penial complex, forming loop or coil before opening to penial lumen via thick-

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FIG. 3. SEM photographs of ***Australocosmica augustae***, n. sp. A–D: Shell, paratype AM C.465175, scale bars = 1 mm; A: Apical view; B: Details of 2<sup>nd</sup> to 4<sup>th</sup> whorl viewed from above; C: Front view; D: Front view showing last whorl and part of aperture; E: Jaw, paratype AM C.465175. Scale bar = 100 µm; F–I: Radula, paratype AM C.465175; F: Central and inner lateral teeth viewed from above. Scale bar = 20 µm; G: Close-up of central and inner lateral teeth; H: Inner and central marginal teeth viewed from above; I: Close-up of central marginal teeth. Scale bars = 10 µm.







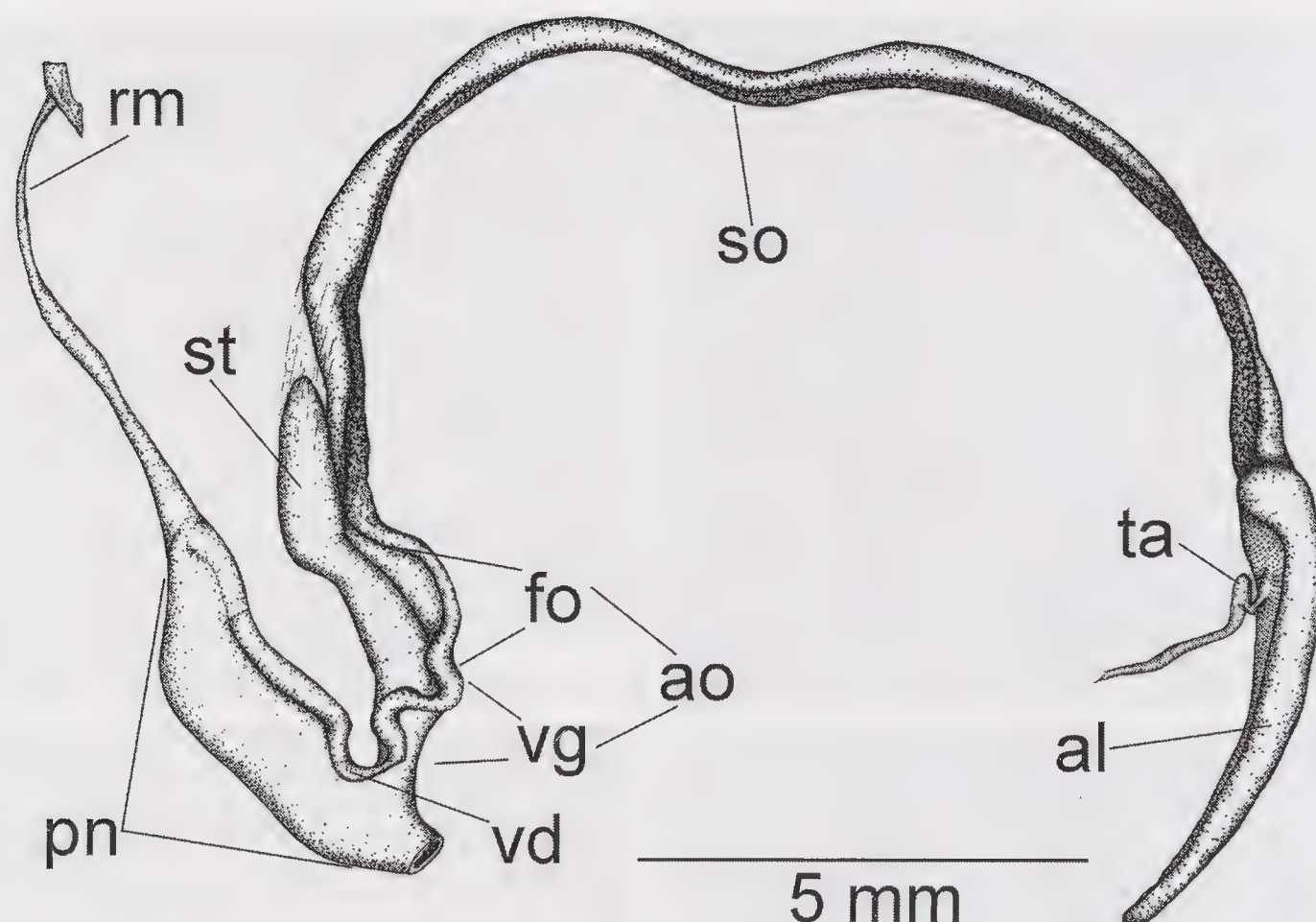


FIG. 4. Genital anatomy of *Australocosmica augustae*, n. sp., paratype AM C.465175. Scale bar = 5 mm. Abbreviations: al – albumen gland, ao – anterior part of oviduct, fo – free oviduct, pn – penis, rm – retractor muscle, so – spermoviduct, st – spermatheca, ta – talon, vd – vas deferens, vg – vagina.

ened, furrowed, collar-like vergic papillum. Inner penial wall smooth. Two longitudinal pilasters form along entire length of the penis wall on each side of opening to vas deferens; additional, weaker pilaster underneath this opening shorter.

Vagina moderately long, posteriorly inflated. Inner wall of vagina and anterior part of oviduct with two or three smooth longitudinal pilasters. Spermatheca short, connected with spermoviduct by delicate connective tissue, reaching distal base of spermoviduct; duct and head slightly differentiated; duct wide, with two smooth longitudinal pilasters; head elongately inflated with longitudinal pilasters, delicate wall. Free oviduct (the part of the oviductal between vagina and the fused spermoviduct), short, more or less straight, about same length as vagina. Spermoviduct much longer than anterior part of oviduct. Albumen gland elongate. Talon situated within first quarter of albumen gland, not embedded in albumen gland; hermaphroditic duct tightly undulating.

**Comparative Remarks:** *Australocosmica augustae* is the type species of the genus. For comparisons with congeneric species, see descriptions below.

***Australocosmica sanctumpatriciusae*, sp. nov.**

**Type Locality:** Western Australia, NW Kimberley, Saint George Basin, St. Patrick Island, 15°21'23"S, 124°57'55"E (KIS 2-64). Vine thicket on steep slopes, sandstone boulders, under rocks in loose soil (leg. V. Kessner, 09.02.2009)

**Holotype** (Fig. 1B): WAM S37666 (preserved specimen).

**Paratypes:** WAM S37637 (two preserved specimens, shells cracked). WAM S49021 (six dried, mostly worn shells), AM C.465173 (five dried, mostly worn shells).

**Additional, non-type Material:** Kimberley mainland, small peninsula ca. 8 km SE of St. Patrick Island, 15°26'02"S, 125°00'23"E: WAM S37638 (three preserved specimens), WAM S49022 (13 dried, mostly worn shells), AM C.465174 (five dried, mostly worn shells).

**Etymology:** The species epithet refers to the name of Saint Patrick (Sanctus Patricius, in Latin), the name patron of St. Patrick Island.



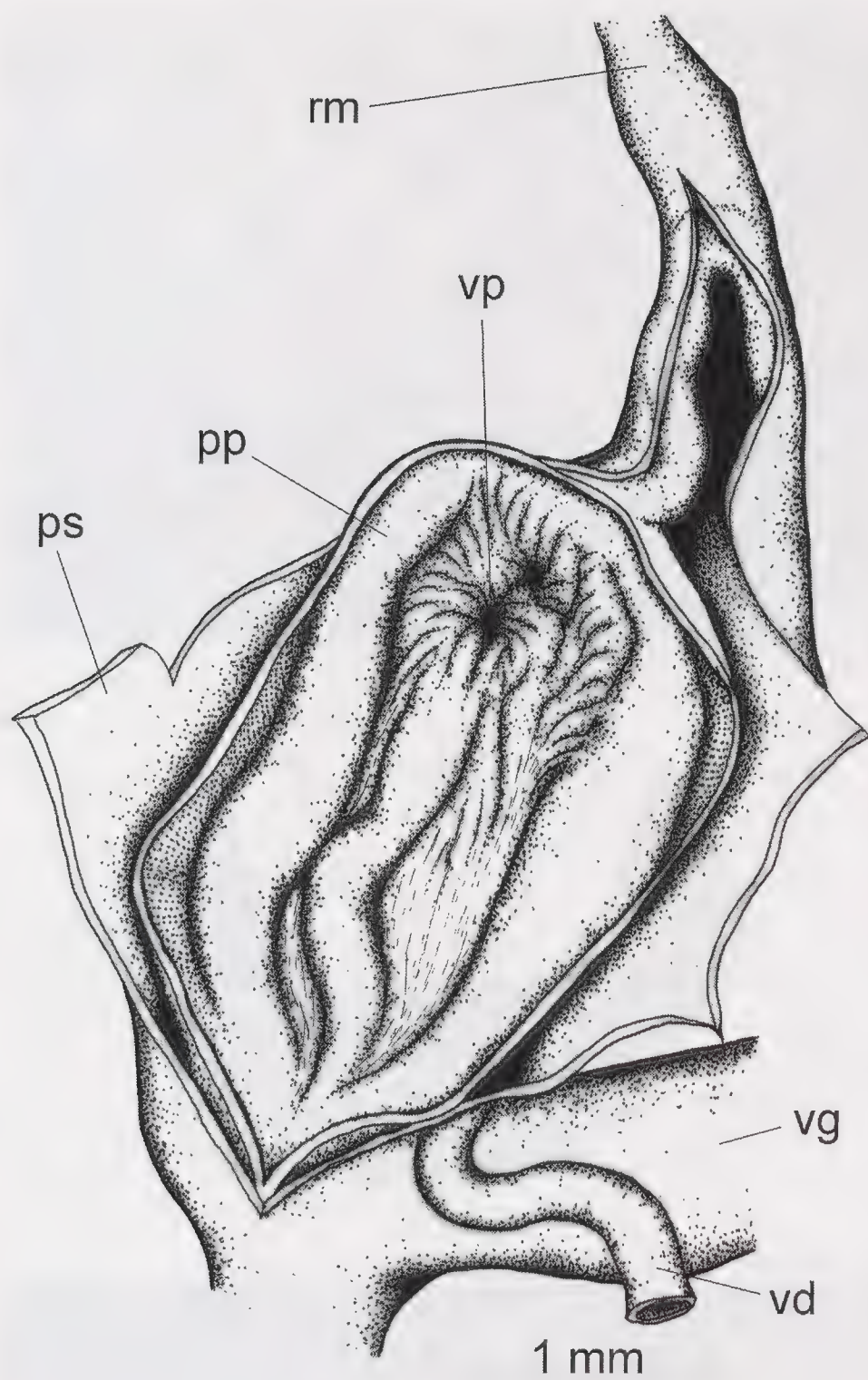


FIG. 5. Penial anatomy of *Australocosmica augustae*, n. sp., paratype AM C.465175. Scale bar = 1 mm. Abbreviations: pp – penial pilaster, ps – penial sheath, rm – retractor muscle, vd – vas deferens, vg – vagina, vp – vergic papillum.

**Description:** *Shell* (Figs. 1B, 6A–C) size between about 11 and 13 mm in height and 15 to 16 mm in diameter (Table 1), broadly conical to semi-globose, with moderately elevated spire, translucent in juveniles to thin in adults. Whorls moderately wide in cross-section, convex, with well-rounded to slightly angulate periphery, slightly shouldered underneath deeply incised suture. Sculpture of very thin, dense, regularly spaced axial ribs. Aperture simple, rounded, no traces of nodes, with thinly callused parietal wall, forming an angle relative to horizontal of 60°. Outer lip thin, very slightly expanded. Umbilicus almost entirely covered by columellar reflection, forming a chink. Colour uniformly dark hornish-brown, inner lip whitish. Periostracum glossy. Protoconch about 2.5 mm in diameter, with about 1.5 whorls, almost smooth, with very fine,

indistinct axial pustulations, transition to teleoconch indistinct.

*Pallial Cavity:* Extending about half a whorl. Mantle pigmented with black spots. Kidney extending about half of pallial cavity.

*Digestive Anatomy* (Fig. 6D–F): Jaw consisting of eight to nine regular, narrow plates ( $n = 1$ ). Radula 3.8 mm long with 115 rows of teeth (30.6 rows/mm) ( $n = 1$ ). Tooth formula =  $C + 14 + 3 + 16$ . Central teeth with sharply pointed, slender mesocone that extends to more than half of basal plate; ectocones vestigial. Lateral teeth with pointed, elongately ovate mesocone, about as long as base of tooth; endocones and ectocones vestigial. Marginal teeth multicuspid, mesocone and endocone similar in length, ectocone smaller than endocone, occasionally subdivided.

*Genital Anatomy* (Figs. 7, 8): Penis straight, more or less as long as anterior part of oviduct. Penis retractor muscle about as long as penis; attached to penial apex near entering of vas deferens. Penial sheath well developed, extending entire length, thin proximally, thick distally. No well-developed epiphallus present. Vas deferens entering penial sheath near apical portion of penial complex, forming loop or coil before opening to penial lumen via conspicuous furrowed, collar-like vergic papillum. Proximal end of inner penial wall with obliquely arranged, fine, irregular transversal folds being distally replaced by large, rhomboid pustules that comprise most of inner penis wall. A well-developed, corrugated pilaster forming underneath opening to vas deferens.

Vagina moderately long, posteriorly inflated. Inner wall of vagina and anterior part of oviduct with many delicate longitudinal pilasters. Spermatheca short, connected with spermooviduct by delicate connective tissue, reaching base of spermooviduct; spermatheca duct and head only slightly differentiated; duct wide, with many delicate longitudinal pilasters; head elongate, with longitudinal pilasters; wall of head delicate. Free oviduct short, slightly shorter than vagina. Spermooviduct much longer than anterior part of free oviduct. Albumen gland short. Talon within first quarter of albumen gland, not embedded in albumen gland. Hermaphroditic duct tightly undulating.

**Comparative Remarks:** Specimens from the mainland (listed under Additional, non-type Material) with slightly smaller shells and narrowly winding umbilicus exhibit a similar pe-



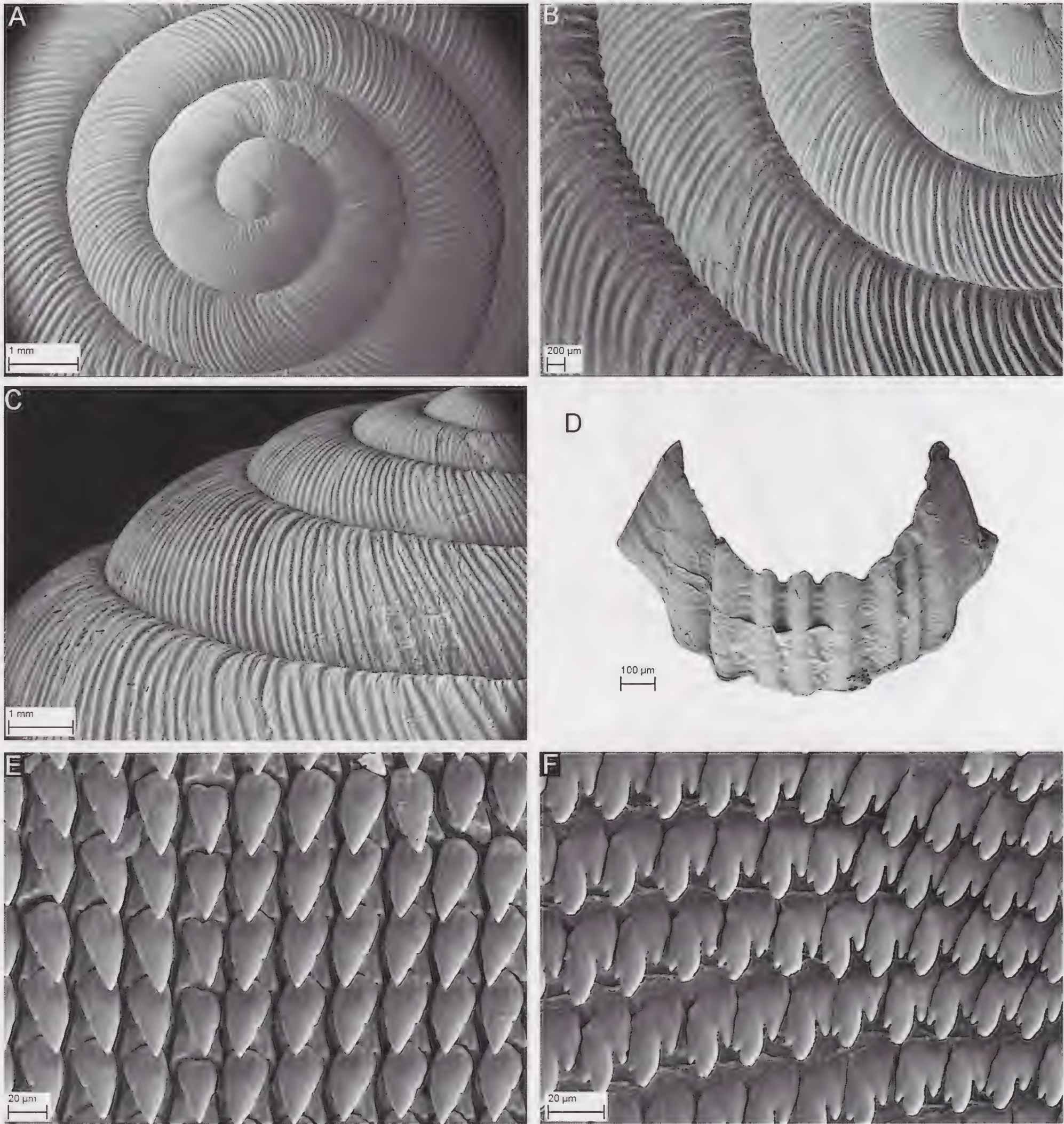


FIG. 6. SEM photographs of *Australocosmica sanctumpatriciusae*, n. sp. A–C: Shell, paratype AM C.465174; A: Apical view, scale bar = 1 mm; B: Details of 2<sup>nd</sup> to 4<sup>th</sup> whorl viewed from above, scale bar = 200 μm; C: Front view, scale bar = 1 mm; D: Jaw, paratype WAM S37637, scale bar = 100 μm; E, F: Radula, paratype WAM S37637, scale bars = 20 μm; E: Central and inner lateral teeth viewed from above; F: Close-up of inner to central marginal teeth.

nia morphology and are genetically not well differentiated. In absence of clearly separating features, they are treated as conspecific with the population on St. Patrick Island. The shell of this species is somewhat intermediate between those of *A. augustae* and *A. vulcanica* with respect to shape and size (Table 1). It tends to be smaller and flatter than *A. augustae*, and larger than *A. vulcanica* (at

least shells from the type locality). Umbilicus of types forms a chink as in *A. augustae* but unlike *A. vulcanica*. However, the shells from the mainland have a narrowly open umbilicus. The most distinctive feature of this species is the dense pustulation of the entire penial wall and the presence of a corrugated pilaster underneath the opening of the vas deferens into the lumen of the penial chamber.



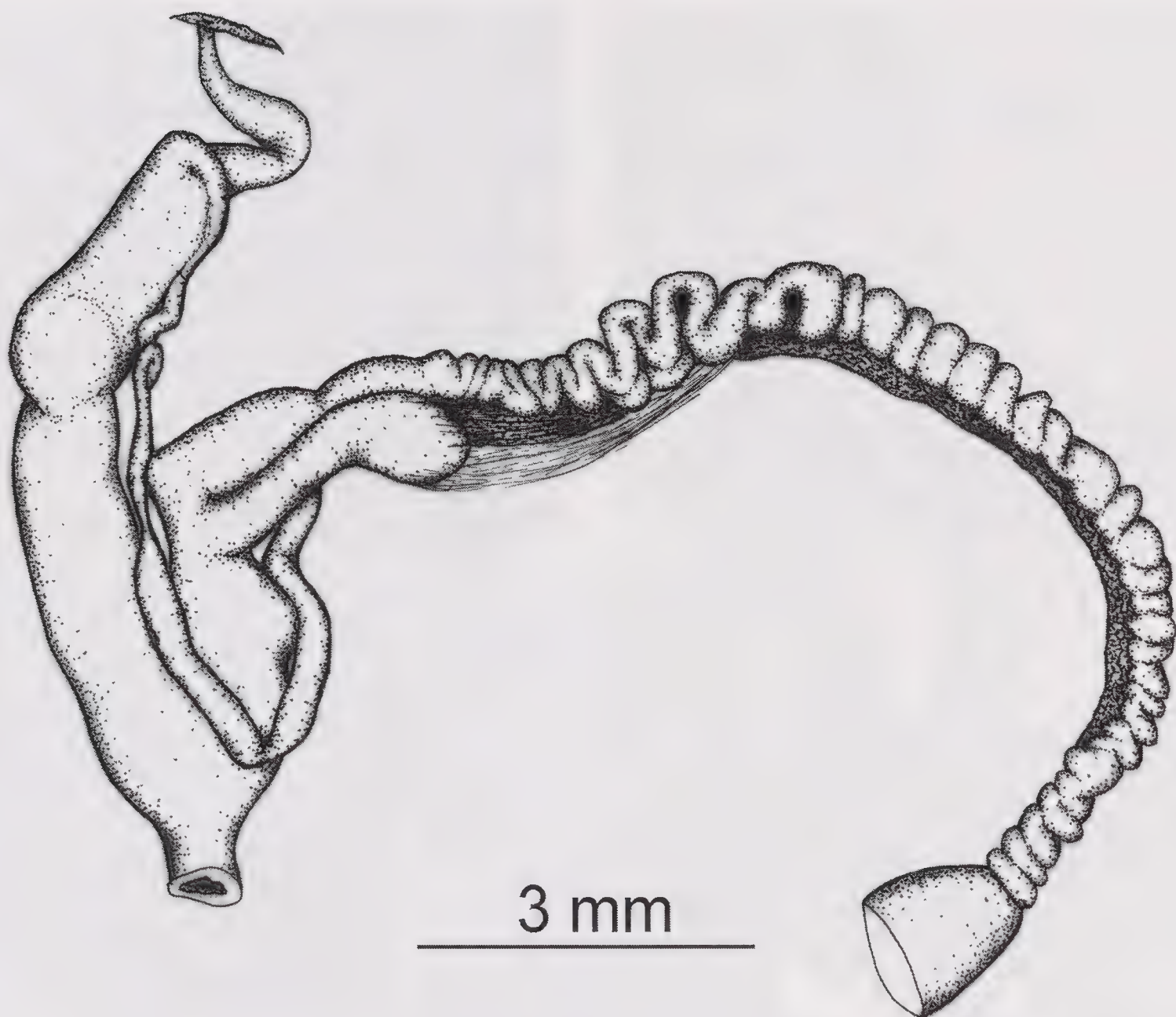


FIG. 7. Genital anatomy of *Australocosmica sanctumpatriciusae*, n. sp., para-type WAM S37637. Scale bar = 5 mm. For labelling of the organs see Fig. 4.

***Australocosmica vulcanica*, sp. nov.**

Type Locality: Western Australia, NW Kimberley, Bonaparte Archipelago, Unnamed Island in Vulcan Islands Group, 1.4 km from NE corner of D'Arcy Island, 15°15'26"S, 124°24'22"E (KIS 2-63). Vine thicket on volcanic scree above rocky beach, in leaf litter amongst boulders; common (leg. V. Kessner, 04.02.2009)

Holotype (Fig. 1C): WAM S37668 (preserved specimen).

Paratypes: WAM S37636 (18 preserved specimens, 3 shells cracked), AM C.465177 (five preserved specimens), WAM S49020 (13 dried, mostly worn shells), AM C.465178 (ten dried, mostly worn shells).

Etymology: The species epithet refers to the Vulcan Island group, where this species is found to dwell on volcanic rocks. The Latin word '*vulcano*' is derived from 'Vulcan', the name of the Roman god of fire.

Description: *Shell* (Figs. 1C, 9A–D) size between about 9 and 11 mm in height and 13 to 15 mm in diameter (Table 1), broadly conical to semi-globose, with moderately elevated spire, translucent in juveniles to thin in adults. Whorls moderately wide in cross-section, convex, with well-rounded to slightly angulate periphery, slightly shouldered underneath deeply incised suture. Sculpture of very thin, dense, regularly spaced axial ribs. Aperture simple, rounded, no traces of nodes, with thinly callued parietal wall, forming an angle relative to horizontal of 60°. Outer lip thin, very slightly expanded. Umbilicus narrowly open to forming a chink. Colour uniformly yellowish brown, inner lip whitish. Periostracum glossy. Protoconch about 2.5 mm in diameter with about 1.5 whorls, almost smooth, with very fine, indistinct axial pustulations, transition to teleoconch indistinct.

*Pallial Cavity*: Extending about half a whorl. Mantle pigmented with black spots. Kidney extending less than half of pallial cavity.

*Digestive Anatomy* (Fig. 9E–H): Jaw consisting of eight regular, narrow plates ( $n =$



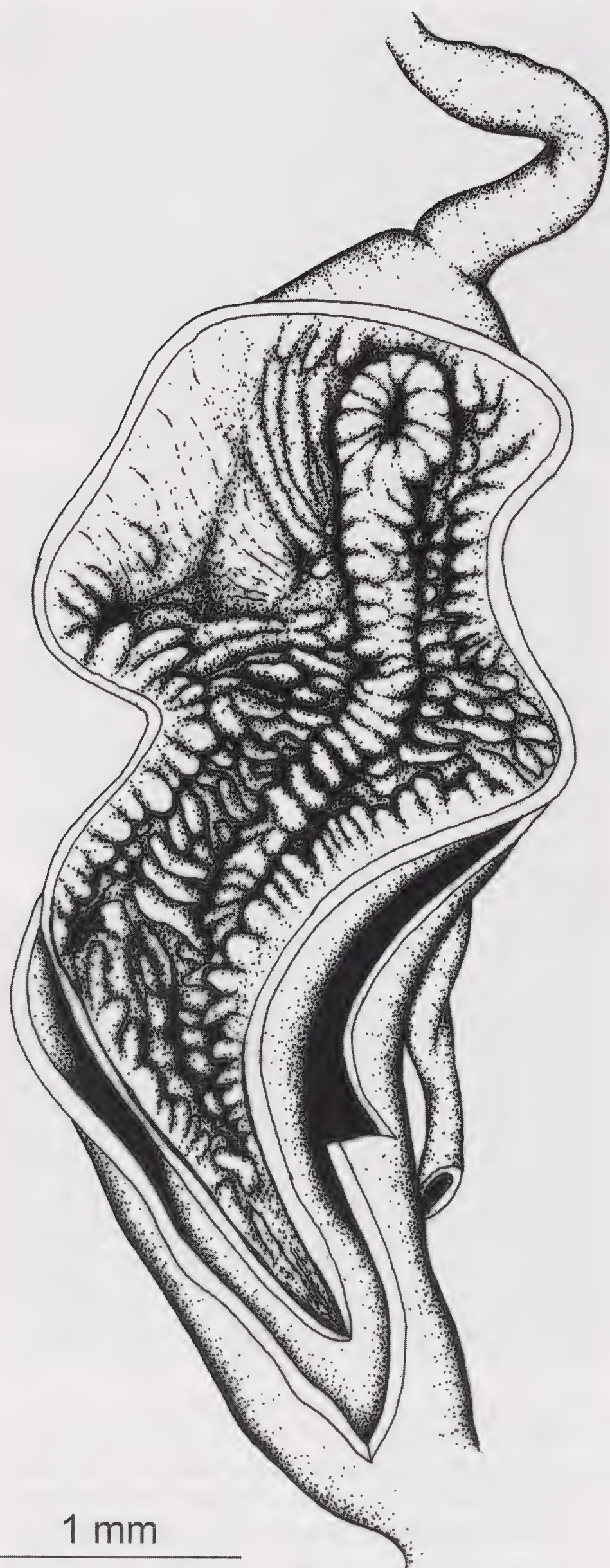


FIG. 8. Penial anatomy of *Australocosmica sanctumpatriciusae* n. sp., paratype WAM S37637. Scale bar = 1 mm. For labelling of the organs see Fig. 5.

2). Radula  $4.3 \pm 0.4$  mm long with  $128 \pm 21$  rows of teeth ( $30 \pm 2$  rows/mm) ( $n = 2$ ). Tooth formula = C + 14 + 2 - 3 + 14 - 16. Central teeth with sharply pointed, slender mesocone that extends to more than half of basal plate; ectocones absent. Lateral teeth with pointed, elongately ovate mesocone, about as long as base of tooth; endocones and ectocones vestigial. Marginal teeth multicuspid, mesocone and endocone similar in length, ectocone smaller than endocone, occasionally subdivided.

**Genital Anatomy** (Figs. 10, 11): Penis strongly inflated; clearly shorter than anterior part of oviduct. Penis retractor muscle about as long as penis; attached to penial apex near entering of vas deferens. Penial sheath well-developed, extending entire length, thin proximally, thick distally. No well-developed epiphallus present. Vas deferens enters penial sheath near apical portion of penial complex, forming loop or coil before opening to penial lumen via thickened, furrowed, collar-like vergic papillum. Parts of inner penial wall pad-like thickened, smooth, delimited by two thick, smooth longitudinal pilasters; distal part with dense pustulation; pustules large, irregularly arranged.

Vagina moderately long, tubular. Inner wall of vagina and anterior part of oviduct with two to three smooth longitudinal pilasters. Spermatheca short, reaching base of spermoviduct, entirely connected with spermoviduct by delicate connective tissue; spermatheca duct and head only slightly differentiated; duct wide, with two smooth longitudinal pilasters; head elongately inflated, with longitudinal pilasters, delicate wall. Free oviduct shorter than vagina. Spermoviduct longer than anterior part of oviduct. Albumen gland elongate. Talon within first quarter of albumen gland, not embedded. Hermaphroditic duct tightly undulating.

**Comparative Remarks:** Shell smaller, flatter, with finer sculpture than *A. augustae* and smaller than *A. sanctumpatriciusae* (Table 1). Umbilicus narrowly winding instead of being entirely covered by columellar reflection as in *A. augustae*. Differs from its congeners by inflated penis proper and pad-like thickening of inner penial wall.



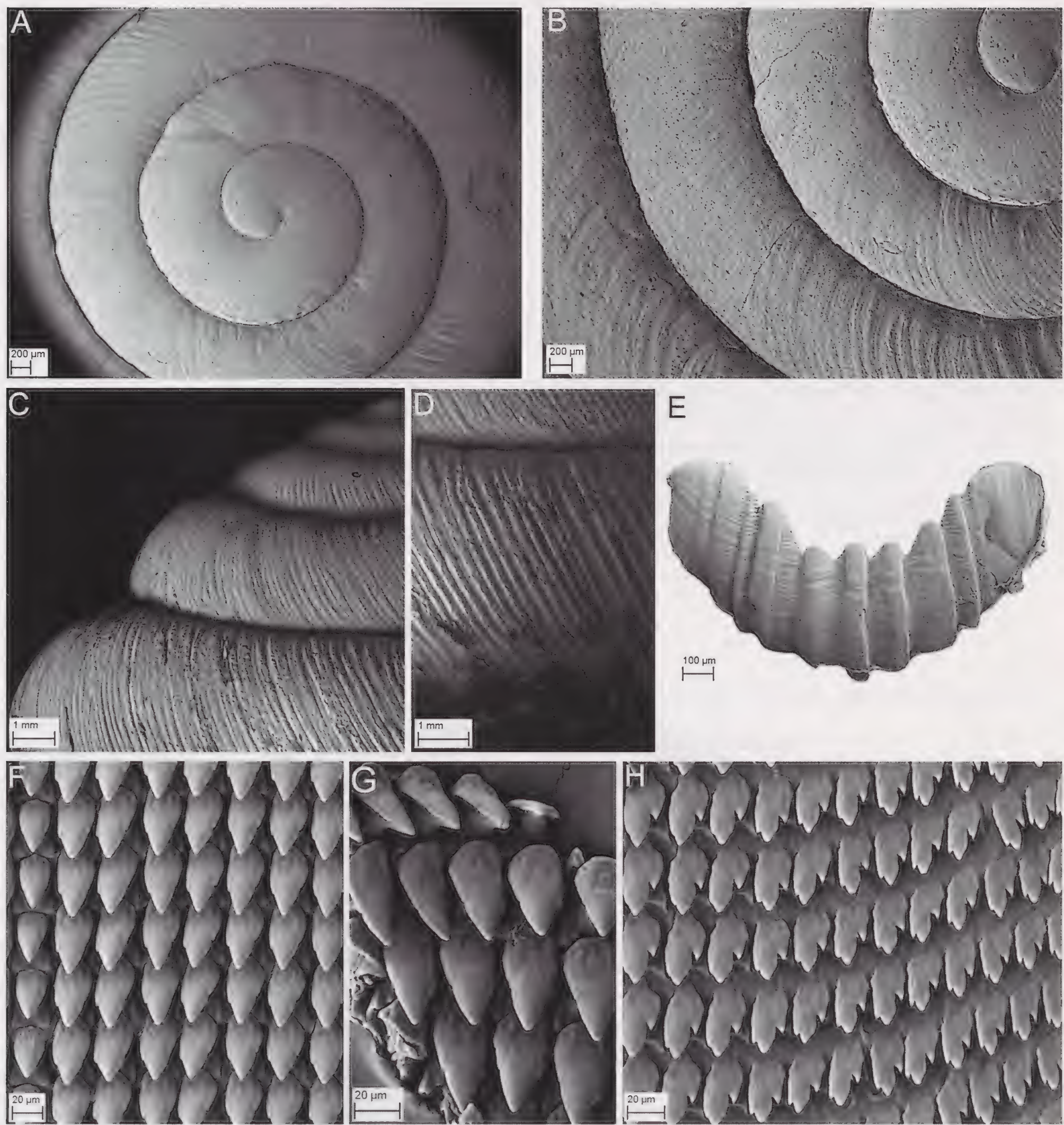


FIG. 9. SEM photographs of *Australocosmica vulcanica*, n. sp. A–D: Shell, paratype AM C.465178; A: Apical view, scale bar = 200 µm; B: Details of 2<sup>nd</sup> to 4<sup>th</sup> whorl viewed from above, scale bar = 200 µm; C: Front view, scale bar = 1 mm; D: Close-up of last whorl; E: Jaw, paratype AM C.465177, scale bar = 100 µm; F–H: Radula, paratype AM C.465177, scale bars = 20 µm; F: Central and inner lateral teeth viewed from above; G: Close-up of central and inner to lateral teeth; H: Inner and central marginal teeth.

*Australocosmica* spec. A

Dry shells: WAM S37162 (Western Australia, NW Kimberley, Bonaparte Archipelago, D’Arcy Island, 15°15’30”S, 124°26’25”E), WAM S37160 (D’Arcy Island, 15°17’29”S, 124°24’00”E).

Comparative Remarks: Shells from D’Arcy Island differ from their geographically closest congener, *A. vulcanica*, by larger size and more elevated spire (Table 1). Since no preserved material is available, their taxonomic status remains questionable.



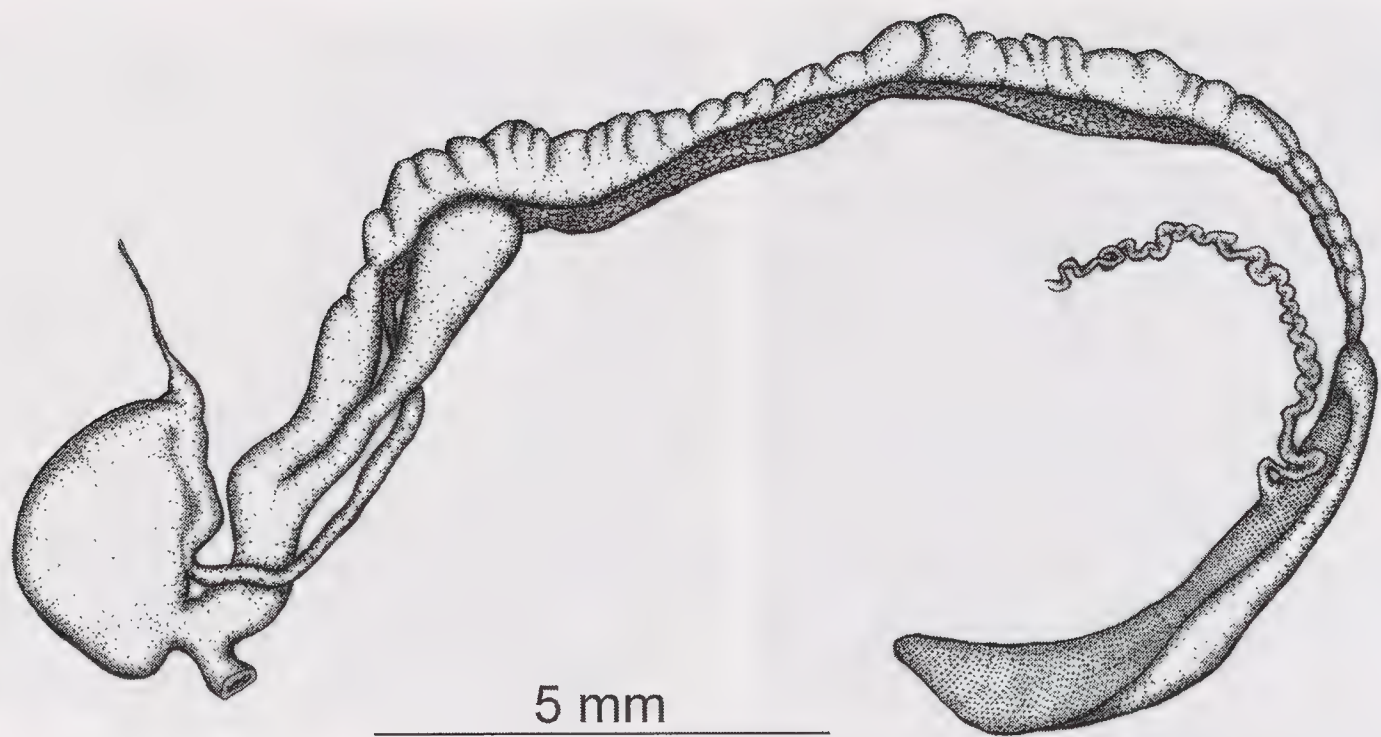


FIG. 10. Genital anatomy of *Australocosmica vulcanica*, n. sp., paratype AM C.465177. Scale bar = 5 mm. For labelling of the organs, see Fig. 4.

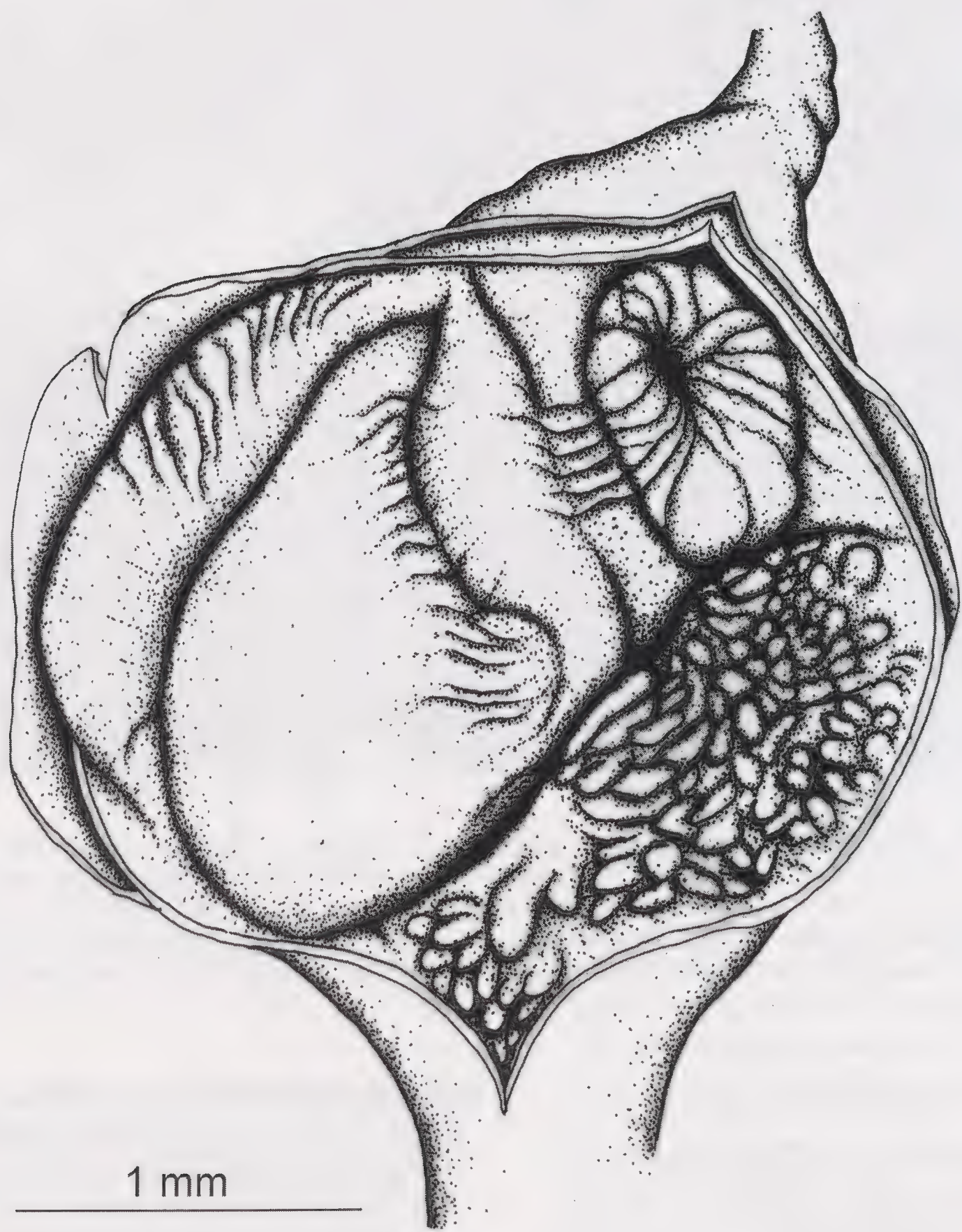


FIG. 11. Penial anatomy of *Australocosmica vulcanica*, n. sp., paratype AM C.465177. Scale bar = 1 mm. For labelling of the organs, see Fig. 5.



Dry, worn shells: WAM S37159 (Western Australia, NW Kimberley, Bonaparte Archipelago, Northern section of Coronation Island, 14°58'48"S, 124°54'46"E). WAM S37158 (Northern section of Coronation Island, 14°58'35"S, 124°54'47"E).

*Australocosmica* spec. C

Dry, worn shells: WAM S49035 (Western Australia, NW Kimberley, mainland, 1.3 km S of halfway Bay, Munster Water, 15°20'15"S, 124°49'23"E).

Comparative Remarks: Three worn and leached shells; average in size and shape, of uncertain affinities.

## Molecular Analyses

An about 800 bp-long fragment of the mitochondrial gene 16S was sequenced from one or two specimens per species in order to infer the rate of genetic divergence. Analyses of a comprehensive data set of about 500 sequences representing more than 175 species of all known camaenid genera from Western Australia have confirmed the monophyly of the new genus *Australocosmica* as delineated herein. This phylogeny, as first shown by Köhler (2009), will be published elsewhere. Here I analysed only five sequences of *Australocosmica* in order to infer

the levels of genetic differentiation among species. The likelihood ratio test revealed the general time reversible model of sequence evolution (GTR+i+ $\Gamma$ ) as the best-fit model. The Maximum Likelihood phylogram revealed all species to represent well-differentiated clades (Fig. 12). Pair-wise comparisons of sequences showed that species were differentiated by means of 15% to 20% uncorrected p-distances, whereas conspecific specimens differed by less than 1%. The present phylogenetic tree has a very restricted taxon sampling and is largely inconclusive with regard to the relationships among the three recognized species. ***Australocosmica sanctumpatriciusae*** is shown at an unresolved, basal position, whereas the two other species are shown in a sister group relationship. However, this relationship receives little nodal support in terms of LR-ELW values.

## DISCUSSION

## Levels of Morphological and Molecular Differentiation

In his revisions, Solem (1979, 1981a, b, 1984) developed a classification of the Western Australian Camaenidae based on features of the shell and genital anatomy. He found that especially penial anatomy is informative on both the species and genus level. So far, the morphology-based classification has not been tested by use of molecular data. However, it has recently been confirmed for *Amplirhagada*, a species-rich genus of Western Australian camaenids, that species usually possess a distinctive penial anatomy, while shell features not always provide reliable means to differentiate species (Köhler, 2010a). *Amplirhagada*

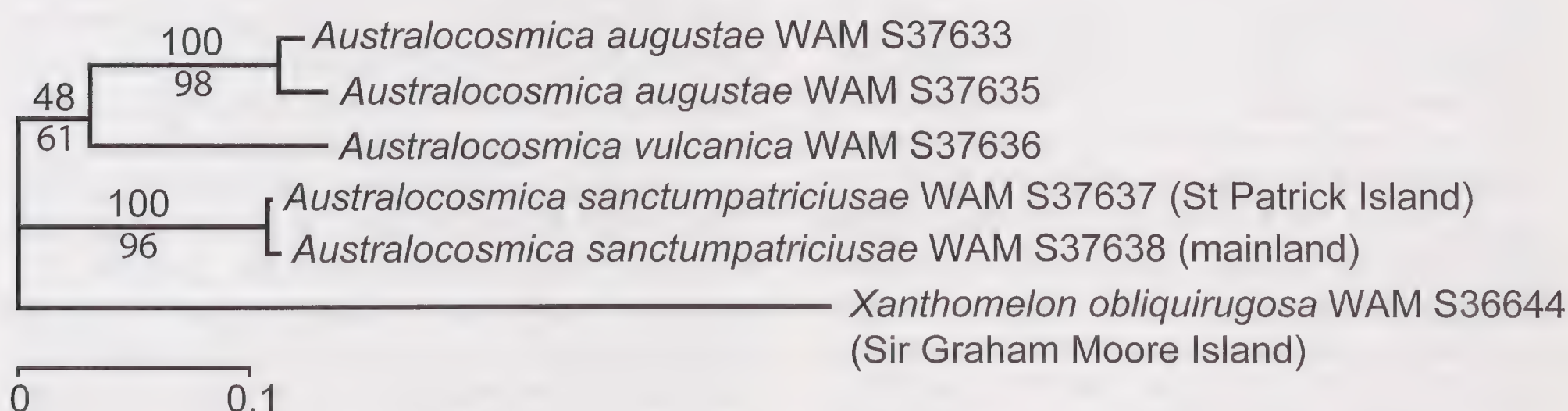


FIG. 12. Maximum likelihood phylogram based on analysis of partial sequences of the mitochondrial gene 16S rRNA. Numbers on branches indicate nodal support by Expected-Likelihood Weights of Local Rearrangements (LR-ELW); numbers below branches indicate bootstrap support.



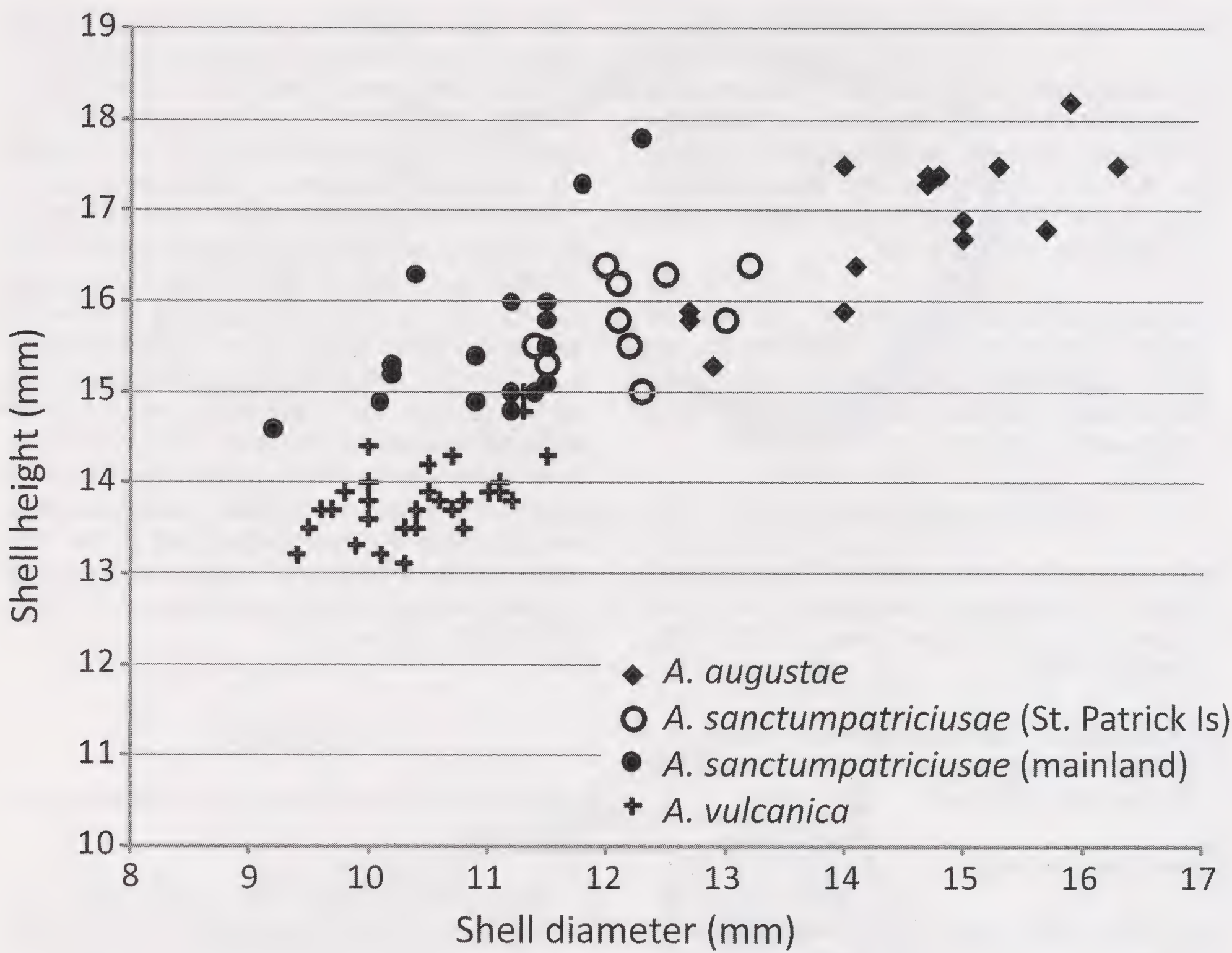


FIG. 13. Morphometrical chart comparing shells of the three newly described species of *Australocosmica* by means of their height and diameter (in mm).

species circumscribed with emphasis on penial anatomy were also found to be characterised by considerable levels of genetic differentiation in mitochondrial markers (of up to 30% Tamura-Nei distances in the cytochrome c oxidase gene, COI). A phylogeny of the Western Australian Camaenidae revealed comparable levels of sequence divergence also for 16S (Köhler, 2009). In addition, corresponding levels of morphological and mitochondrial differentiation were also observed in camaenid species of *Torresitrachia* Iredale, 1939, from limestone outcrops in the Northern Territory (Willan et al., 2009). These two systematic studies mainly addressed the levels of differentiation between species by using only few representative specimens of each species. However, a study that included a large number of specimens from various populations of *Amplirhagada* from 16 islands in the Kimberley showed that the genetic variation within populations was generally low, while populations from different islands were always separated by considerable

genetic distances (Johnson et al., 2010). This finding underscores the utility of mitochondrial markers for species recognition in this group of land snails. In contrast to mitochondrial data and penial anatomy, shell morphology has not been as informative on the species level because of a large overlap of the variation within and between populations and species. Therefore, there is evidence from several groups that in Western Australian Camaenidae levels of morphological (with respect to penial anatomy) and molecular differentiation are closely linked, while shells are less informative. The observations in *Australocosmica* do well correspond with these findings. Species recognised by their penial anatomy are also well differentiated in the mitochondrial marker 16S. By contrast, while species differ to some degree in size and shape of their shells, they also show considerable variation within populations and a large overlap in the morphological ranges of species (Fig. 13). This is most conspicuously demonstrated for *A. sanctumpatriciusae*,



which has a comparatively small shell with narrowly open umbilicus on St. Patrick Island and larger shells with an umbilicus entirely covered by the columellar reflection on the mainland. Consequently, shell morphology is mainly informative at the generic level whereas it is of low taxonomic value at the infrageneric level.

#### Diversity and Distribution of *Australocosmica*

The monophyly of *Australocosmica* has received high nodal support in a comprehensive phylogeny of the Western Australian Camaenidae (Köhler, 2009). It was therefore not of concern here. *Xanthomelon* was used as out-group, because it was found to be member of a clade of taxa that forms the sister group of *Australocosmica*. The considerable genetic distances between all taxa included in the sequence data set may have caused long-branch attraction. The lacking support for the monophyly of *Australocosmica* in the tree presented here is attributed to this phenomenon. It is not considered to indicate problems with the correct delineation of the genus *Australocosmica*.

The distribution of *Australocosmica* is apparently restricted to the coastal regions and offshore islands of the northwestern Kimberley region in or near the Prince Regent Reserve. Mapping of all available distribution data, which includes also undescribed species found here and listed by Solem (1991), suggests that the genus occurs roughly between the York Sound in the north and the Collier Bay in the south (Fig. 1). In addition to the three species described here, there are several further species that were preliminarily delineated by Alan Solem under manuscript names but were not studied in detail. Because Western Australian Camaenidae usually are narrow range endemics (Solem, 1991), the manuscript species listed by him likely are further distinct species. These are likely endemic on Albert (spec. 80), Coronation (spec. 78), Buffon (spec. 77), Maret (spec. 79), and D'Arcy islands (spec. 76) (including satellite islets), as well as on the mainland opposite of Augustus Island (spec. 39) and around the Walcott Inlet (spec. 40). As by now, the relation of three described to possibly seven to ten undescribed species of *Australocosmica* underscores that there is a considerable proportion of formally unknown species diversity in the Kimberley with the number of undescribed species actually exceeding that of the described species. This holds not only true for *Australocosmica* but probably also for other genera in the group.

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